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DESIGN OF A SAFE SYSTEM FOR CONDUCTING PRESERVATION OF VEHICLE FUEL TANKS

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DESIGN OF A SAFE SYSTEM FOR CONDUCTING PRESERVATION OF VEHICLE FUEL TANKS

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76

FOREWORD

The research discussed in this report was accomplished as part of the Safety Engineering Graduate Program conducted jointly by the USAMC Intern Training Center and Texas A&M University. As such, the ideas, concepts and results herein presented are those of the author and do not necessarily reflect approval or acceptance by the Department of the Army.

This report has been reviewed and is approved for release. For further information on this project contact Dr. George D.C. Chiang, Intern Training Center, Red River Army Depot, Texarkana, Texas 75501.

Approved:

George D.C. Chiang, Chief
Department of Safety Engineering

For the Commander

James L. Arnett, Director, ITC

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This paper develops a design for a safe system for conducting preservation of fuel tanks of vehicles which are to be shipped or stored. A preliminary hazard analysis was performed to provide initial hazard information prior to the design. Failure mode and effects analysis and fault tree analysis were performed to discover and correct any weaknesses in the design. Fire and explosion were found to be the primary hazards associated with the preservation of vehicle fuel tanks. The designed system and the present system were compared as to

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE relative degree of hazard. The conclusion was made that the designed system is safer in terms of fire and explosion hazards than the presently used system.

ABSTRACT

Research Performed by James M. Rummer

Under the Supervision of Dr. R.L. Street

This paper develops a design for a safe system for conducting preservation of fuel tanks of vehicles which are to be shipped or stored. A preliminary hazard analysis was performed to provide initial hazard information prior to the design. Failure mode and effects analysis and fault tree analysis were performed to discover and correct any weaknesses in the design. Fire and explosion were found to be the primary hazards associated with the preservation of vehicle fuel tanks. The designed system and the present system were compared as to relative degree of hazard. The conclusion was made that the designed system is safer in terms of fire and explosion hazards than the presently used system.

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During the course of this work, the author was employed by the U.S. Army as a career intern in the AMC Safety Engineering Graduate Program. He is grateful to the U.S. Army for the opportunity to participate in the Program.

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Military vehicles must be properly prepared to resist corrosion during periods of shipment or storage so that they will be operational when the need arises. This report will discuss and analyze the hazards associated with preservation of fuel tanks of military vehicles and offer a design of a safe system for conducting preservation of vehicle fuel tanks. This report is a limited engineering study which will not consider economic factors.

A general description of this requirement is found in Military Specification, Vehicles, Wheeled: Preparation for Shipment and Storage, MIL-V-62038C. The procedure, outlined in the specification, is to first drain the fuel tank of fuel (gasoline or diesel fuel) by removing the fuel drain plug. The drain plug is then scheduled to be reinstalled and the fuel tank filled with lubricating oil conforming to type I, grade 10 of MIL-I-21260 (6)* and again drained and allowed to stand with the drain plug removed until oil flow ceases. Finally, the plug and tank filler cap are to be coated with the same oil and reinstalled.

Drained preservative oil may be reused for processing other fuel tanks, provided not more than 10 percent of the fluid is fuel. The specification provides that this be determined by sampling the preservative oil drained from the fuel tanks of one out of five vehicles. The gravity value is determined using an American Petroleum Institute hydrometer and compared to a value obtained using a mixture of nine parts new (unused) preservative

*Numbers in parentheses refer to numbered references in the List of References.

oil and one part of fuel (5).

During early investigations of the preservation of vehicle fuel tanks at Red River Army Depot (RRAD), Texarkana, Texas, the operation was being conducted indoors. Two 500 gallon, shop fabricated, portable tanks, fitted with general purpose electric motor driven pumps, were being used to fill the fuel tanks with preservative oil.

A later investigation of the vehicle fuel tank operation at RRAD was made to obtain more details. However, it was discovered at this time that the operation was moved outside in a large open area. Vehicles were being driven to this area and lined in a row. A 2500 gallon tanker truck, equipped with a gasoline motor driven pump, pumped the gasoline out of the fuel tanks of the vehicles into its tank. A second 2500 gallon tanker truck filled the fuel tanks using its standard power-take-off pump. After all the vehicle fuel tanks in the row were filled the second truck pumped the preservative oil back into its holding tank using a gasoline motor driven pump which was mounted near the top of one side of the tanker truck. The foreman of the operation stated that he planned to replace the gasoline motors with electric motors using a gasoline powered generator towed behind the tanker trucks as a power source.

The tanker trucks were not designed to be filled by having a fluid pumped from fuel tanks of vehicles into their tanks. Each tanker truck was modified to allow this. A gasoline motor-driven pump was added to each tanker truck. If the pump seals were to fail and gasoline leaked onto a hot motor, a catastrophic fire could result.

Neither tanker truck was designed to deliver fluids to individual vehicles. Repeated transfer of fuels increases the exposure to hazardous fuel vapor-air mixtures and increases the possibility that bonding wires will not be properly attached.

The relocation of the vehicle fuel tank preservation facilities to the outside seems to be a safety improvement. Yet, using equipment for purposes other than intended can be very dangerous. Equipment and procedures, especially designed for vehicle fuel tank preservation would be safer and more efficient.

Chapter II is a discussion of the properties of flammable liquids which will be helpful in analyzing the hazards of a system for conducting preservation of vehicle fuel tanks. The hazards are analyzed and the design of a preservation system proposed in Chapter III. Chapter IV contains a safety analysis of the system design. The designed system and the present system are compared as to relative degree of hazard in Chapter V. Chapter VI presents the author's conclusions regarding the design of the preservation system regarding safety and recommendations for further research and study. Techniques for predicting flashpoints of oil-gasoline mixtures are discussed and presented in the Appendix.

CHAPTER II

CHARACTERISTICS OF FLAMMABLE LIQUIDS

This chapter will discuss the properties of flammable liquids which need to be considered in the hazard analysis of a system for conducting preservation of vehicle fuel tanks. The intent is to familiarize the reader with the nature of flammable liquids and provide an appreciation of their hazards.

The flashpoint of a liquid is the lowest temperature at which the vapor pressure of the liquid is just sufficient to produce an ignitable mixture with air at the lower limit of flammability (21). This is the principal factor in determining the hazards of flammable liquids (16). All liquids with flashpoints below 100 degrees Fahrenheit are called Class I flammable liquids, those with flashpoints from 100 to 140 degrees Fahrenheit are called Class II combustible liquids, and those with flashpoints over 140 degrees Fahrenheit are called Class III combustible liquids (7). Title 29 of the Code of Federal Regulations (paragraph 1910.106) sets forth special procedures for the handling and use of flammable and combustible liquids.

Liquid fuels and lubricants will not burn or explode while in a liquid state. It is the vapor which burns or explodes when mixed with air in the proper proportions and exposed to a source of ignition. For gasoline the proper proportions which result in explosive conditions (flammable limits) are about 1.4 percent to 7.6 percent by volume (21). Distinct from an explosion of a flammable vapor-air mixture inside a container is the internal buildup of pressure which results in rupture of the vessel.

Under most conditions, the principal hazard in handling fuel products occurs during transfer when vapor will most likely be present in the proper proportions in the presence of outside ignition sources. Ventilation is of primary importance to prevent buildup of concentrations of vapor-air mixtures. Most flammable liquids produce heavier-than-air vapors which tend to settle on the floor or ground. Such vapors may flow along the ground for long distances, be ignited, and flash back (21).

Normally, gasoline in an enclosed container forms a vapor-air mixture which is too rich to ignite. The flammable limits of gasoline correspond to a temperature range of approximately minus 55 to plus 15 degrees Fahrenheit (1). Diesel fuel has a very low vapor pressure and a high flashpoint of 130 degrees Fahrenheit (18). Preservative oil is less volatile than diesel fuel and has a flashpoint of 400 degrees Fahrenheit (6). Because of their extremely low volatility diesel fuel and preservative oil form vapor mixtures in air that are too lean to ignite at ordinary temperatures.

When gasoline is mixed with preservative oil (or with diesel fuel), the flashpoint of the mixture may be such as to make the mixture hazardous in ordinary use. The gasoline can act as a fuse to ignite the higher-flashpoint preservative oil (16). Four samples of used preservative oil, taken by the Red River Army Depot Safety office on two different days, confirmed this fact. The samples were analyzed by the Red River Army Depot Chemical Laboratory Section. The flashpoints of the samples were determined to be 54, 41, 70, and 85 degrees Fahrenheit. These temperatures indicated that the vapor-air mixtures of these samples were within the flammable range, and a flammable mixture was present above the liquid in the storage tank at the time the samples were taken.

Fuels are subject to buildup of static electric charges generated by the flow of fuel in pipes. Spark discharges may have sufficient energy to ignite flammable vapor-air mixtures. The greatest danger from this is during the early stages of tank filling operations, before the fill nozzle is submerged. With gasoline, a spark will generally not cause an ignition because the vapor-air mixture is too rich. However, this may not be the case with preservative oil contaminated with gasoline. A spark in a tank with this mixture might cause a severe explosion (18).

The procedures presently used at RRAD specify that bonding wires will be used between the tanker truck and the vehicles being serviced. Inspection has shown that if the tanker truck is not properly positioned, the bonding wires are ignored.

A system designed for conducting preservation of vehicle fuel tanks would contain self-bonding hoses and nozzles such that bonding wires would serve only as safety back-ups. It would also be desirable to maintain the flashpoint of the preservative oil at a temperature higher than normally encountered (120 degrees Fahrenheit). A complete design is specified in Chapter III.

CHAPTER III

HAZARD ANALYSES AND DESIGN

Hazard analyses are performed to identify hazardous conditions so that action can be taken to eliminate or control them. This chapter will present a preliminary hazard analysis, a design of a system for conducting preservation of vehicle fuel tanks based upon the preliminary hazard analysis, a failure modes and effects analysis of the design, and a fault tree analysis based on the failure modes and effects analysis.

Preliminary Hazard Analysis

Preliminary hazard analyses are performed to obtain an initial safety evaluation of a system, process, or product. It is being performed here before the design so that safety considerations can be systematically included in the design.

The preliminary hazard analysis will be limited in scope following the assumptions that:

(1) Bulk storage of gasoline and bulk storage of preservative oil will be required.

(2) One or more components will use electricity as a power source.

(3) Some type of pumping device will be used.

Aside from these general assumptions, no design is assumed at this time.

Design of a Vehicle Fuel Tank Preservation System

The design of the system for conducting preservation of vehicle fuel tanks must protect against fire and explosion, a fact established by the preliminary hazard analysis. As the design concept is presented, fire safety features of the proposed design are described.

PRELIMINARY HAZARD ANALYSIS

Subsystem: Preservative oil storage tank

HAZARD	CAUSE	EFFECT
Corrosion	Reaction with air	Leakage of oil Possible collapse of tank with major oil spill
Rupture of tank	Excess tank pressure High temperature combined with unvented tank Tank weakened by corrosion	Major spill of oil Combined with ignition source results in major fire
Leakage	Wear or deterioration Worn gaskets or seals Failure of welded seams Rupture from vibration or fatigue	Combined with ignition source results in fire
Explosion	Static discharge combined with explosive vapor-air mixture	Personnel death or severe injury Loss of system

PRELIMINARY HAZARD ANALYSIS

Subsystem: Fuel tank filling system

HAZARD	CAUSE	EFFECT
Static electricity	Flow of fluid through hoses and pipes	Combined with proper vapor-air mixture results in explosion or fire
Spillage of oil	Failure of valve to close Careless procedure by operator	Combined with source of ignition results in fire Makes surfaces slippery resulting in injuries to personnel
Stoppage of oil	Valve failure	System failure

PRELIMINARY HAZARD ANALYSIS

Subsystem: Gasoline Draining System

HAZARD	CAUSE	EFFECT
Fire	Source of ignition near drain (static electricity, cigarettes, open flame, welding operations)	Severe injuries to personnel Loss of system
Explosion	Activation of vapors in confined spaces	Death or severe injuries to personnel Loss of system
Rupture of gasoline storage container	Elevated temperature Deterioration of container	Loss of gasoline Combined with ignition source results in fire and/or explosion
Leakage	Deterioration of seals Structural failure	Release of gasoline Combined with ignition source results in fire and/or explosion

PRELIMINARY HAZARD ANALYSIS

Subsystem: Pump and motor

HAZARD	CAUSE	EFFECT
Ignition of flammable vapors	Vapors in contact with spark	Injuries to personnel System loss
Explosion	Fatigue failure of rotati g parts	Injuries to personnel System loss
Leakage	Deterioration of seals	Combined with ignition source results in fire

PRELIMINARY HAZARD ANALYSIS

Subsystem: Electrical

HAZARD	CAUSE	EFFECT
Short circuit	Erroneous connection Faulty connection Dirt Contamination Corrosion	Combined with explosive vapor-air mixture results in explosion or fire
Power source failure	Short circuit	System failure

PRELIMINARY HAZARD ANALYSIS

Subsystem: Fuel lines and connections

HAZARD	CAUSE	EFFECT
Leakage	Loose connections Fatigue Vibration	Combined with ignition source results in fire

As previously stated, a desirable feature of the preservation system is to maintain the flashpoint of the preservative oil at a temperature higher than normally encountered. However, equations from the literature (11,22), predict flashpoints of preservative oil-gasoline mixtures below temperatures normally encountered. These predicted flashpoints indicate that the vapor-air mixtures above preservative oil, which has been contaminated with even small amounts of gasoline, are dangerously explosive. The predictive equations and a graph of predicted flashpoints are presented in the Appendix. Since the flashpoint of preservative oil, contaminated with gasoline, cannot be maintained above temperatures normally encountered, only fresh preservative oil is used to preserve vehicle fuel tanks in the designed system.

The design consists of a gasoline drain area with an underground storage tank (Figure 1) and a preservation area (Figure 2) with an underground preservative oil storage tank, a pump, an automatic sprayer, an oil drain, and an underground used oil storage tank.

The proposed system would operate in the following manner. A worker drives the vehicle, which is to be processed, to the gasoline drain area where the fuel tank drain plug is removed and the fuel drained into the underground gasoline storage tank (Figure 1). The vehicle is then towed to the preservation area (Figure 2) and positioned over the drain of the used oil storage tank. The fuel tank fill cap is removed and the automatic sprayer head is screwed onto the fuel tank (see Figure 3). The operator pushes the control switch and 3/4 gallon (or quantity determined from experimental results for each vehicle) is sprayed evenly on the inside surfaces of the fuel tank and allowed to drain through the fuel tank opening simultaneously. Fifteen seconds after the spray has ceased another

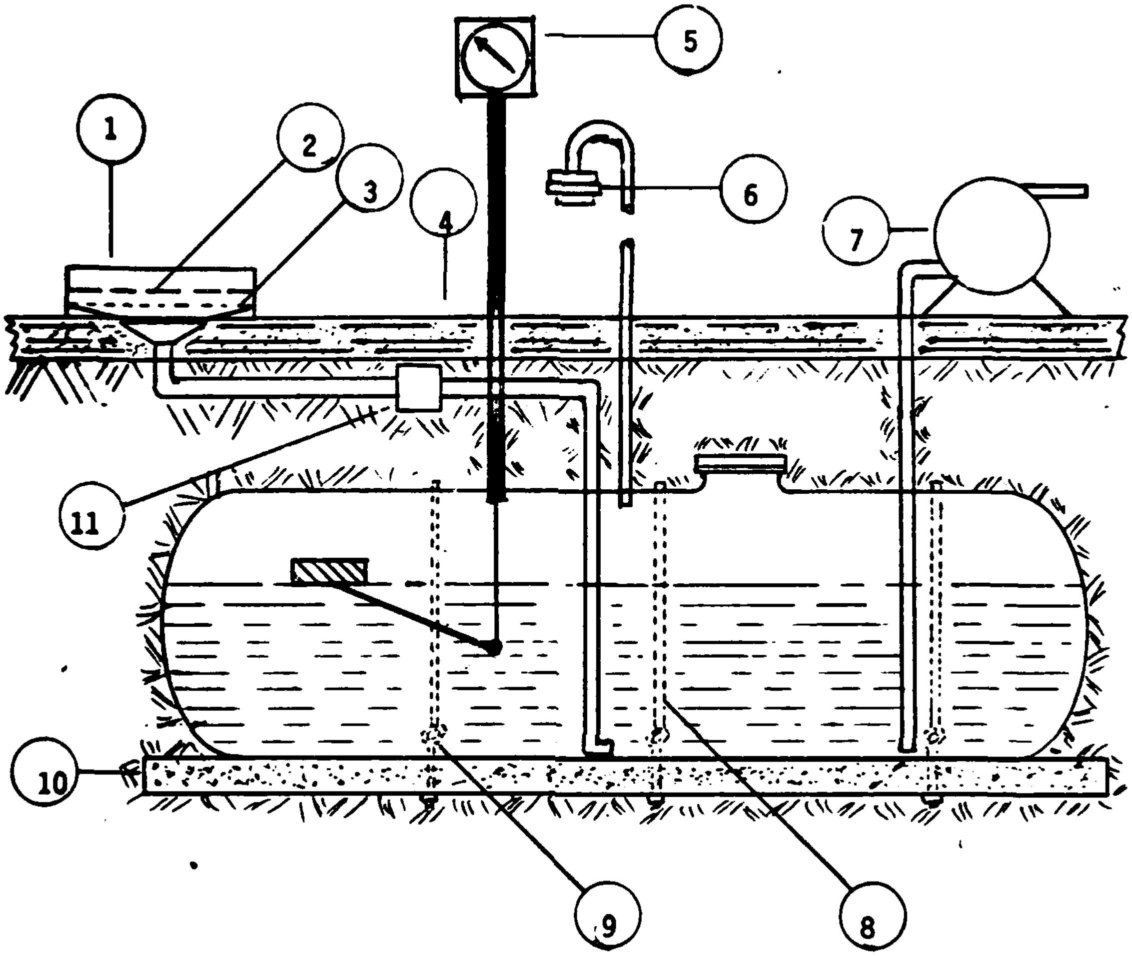


FIGURE 1

DETAILS OF GASOLINE AND USED PRESERVATIVE OIL TANKS

1. Drain pan
2. Grate
3. Screen
4. Six inches of reinforced concrete
5. Gauge
6. Flame arrester on vent pipe
7. Positive-displacement transfer pump
8. Anchor strap
9. Anchor rod
10. Concrete anchor
11. Flame arrester

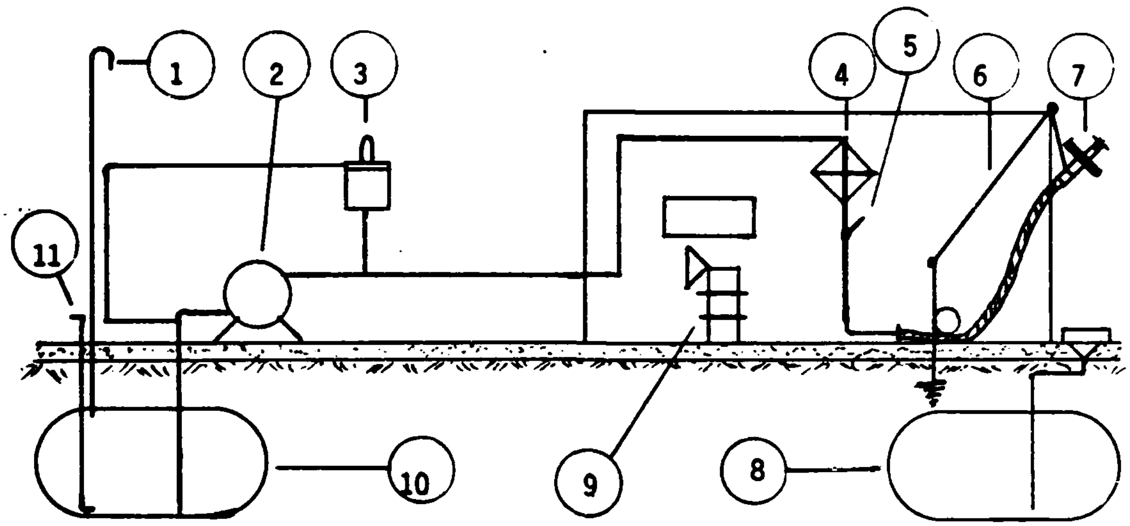
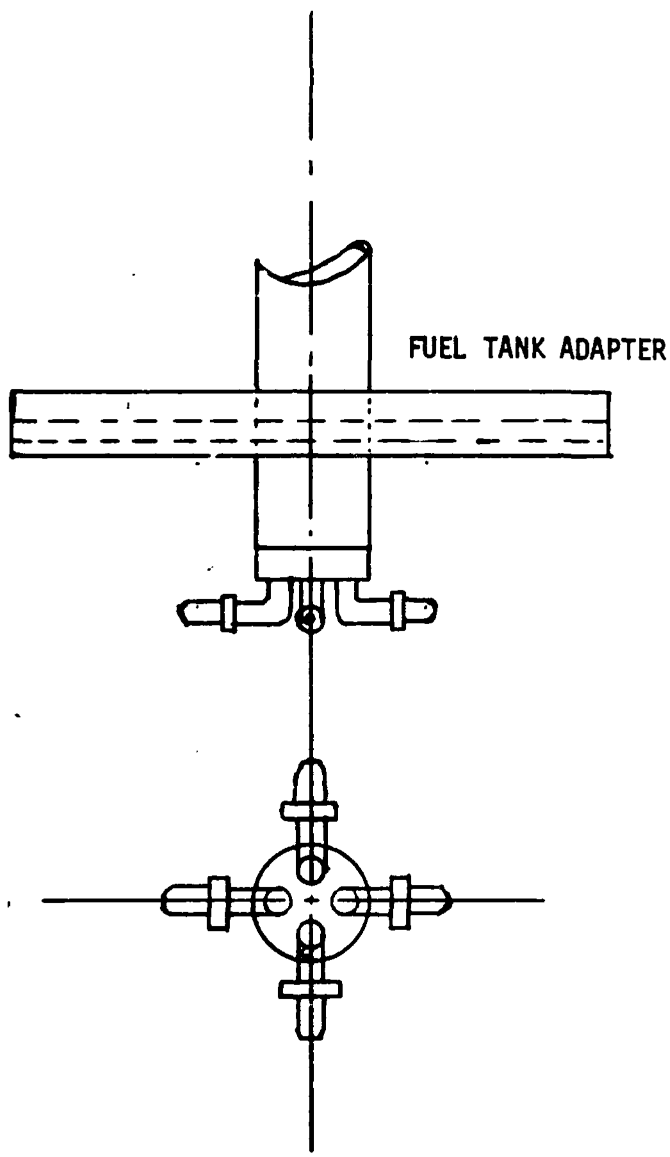


FIGURE 2

PRESERVATIVE OIL SPRAY SYSTEM

1. Vent pipe
2. Positive-displacement pump
3. Relief valve
4. Automatic flow controller
5. Emergency shutoff
6. Take-up cable for flexible hose
7. Spray nozzle
8. Used preservative oil storage tank
9. Class B portable fire extinguisher
10. Fresh preservative oil storage tank
11. Fill pipe



SOLID-CONE NOZZLE ARRANGEMENT

FIGURE 3

PRESERVATIVE OIL SPRAYER HEAD

3/4 gallon of preservative oil is sprayed as described. Fifteen seconds after the second spray has ceased the process is repeated for the third and last time. The oil is allowed to drain for fifteen seconds and then the drain plug and filler cap are replaced and the vehicle is towed away. The used oil storage tank details are identical to the gasoline storage tank details as shown in Figure 1.

The safest practice is to store flammable liquids in buried cylindrical tanks out of doors (8). Since each of the underground tanks will be subjected to heavy traffic over them, the tanks should be provided with at least 18 inches of tamped earth plus 6 inches of reinforced concrete. This protection should extend at least one foot beyond the outline of each tank. Each tank should be anchored (see Figure 1) to prevent flotation during periods of high water and flooding. A 1½ inch vent pipe should extend at least 6 feet above the reinforced concrete. Flame arresters should be used in the drain pipes and the vent pipes of the gasoline and used oil storage tanks. A course screen should be provided on the vent of the preservative oil storage tank to keep our foreign material.

A positive-displacement pump should be used to pump the preservative oil in the preservative oil spray system. A relief valve, rated at 15 psi, should be provided downstream from the pump to regulate the pressure of the system. The relief valve discharge should be piped to the suction side of the pump as shown in Figure 1. Since the preservative oil spraying system operates at 15 psi, the piping should be static tested at 23 psi before placing it in service. A safety shutoff should be provided in the event of emergency.

The piping in the preservative oil spray system should be schedule 40 wrought-iron pipe with standard-weight 125 pound steel or malleable-iron fittings. Welded joints and flanged connections should be used for ease of dismantling to avoid subsequent in-place cutting and welding. Piping should be supported with adequate, non-cumbustible, high-melting-point supports to prevent excessive vibration and strain. Allowance for thermal expansion should be made by using an expansion bend in the piping. Mechanical guards, conspicuously painted with black and white diagonal stripes, should be provided to protect the surface piping.

In addition to using flame arresters in the drain pipe and in the vent pipe of the used preservative oil storage tank, "reticulated foam" should also be used. "Reticulated foam" is a sponge-like plastic which has small interconnecting passages which act as a three-dimensional flame arrester in the tank (3). The blanket of foam quenches any incipient fire before it can propogate and explode the tank. Fuel flows freely through the foam, which occupies about 5 percent of the volume of the tank. No special pump or other devices are required. Foam is specified in the used preservative oil tank because explosive vapor-air mixtures may exist in this tank, whereas the vapor-air mixtures in the gasoline and fresh preservative oil tanks should be either too rich or too lean to ignite.

Since Texarkana and surrounding area can expect approximately 60 thunderstorms each year (8), low-breakdown lightning arresters and wave-sloping capacitors should be installed at the motor terminal of all electric motors used (see Figure 4). The nearest water main, within 75 feet should be used as the ground connection. If a main is not available, driven rods or buried plates should be used as the ground connection. Each item to be grounded should be connected by a substantial copper or brass ground strap clamped to a space on the water main which has been thoroughly cleaned. The strap should be secured by two brass or bronze bolts.

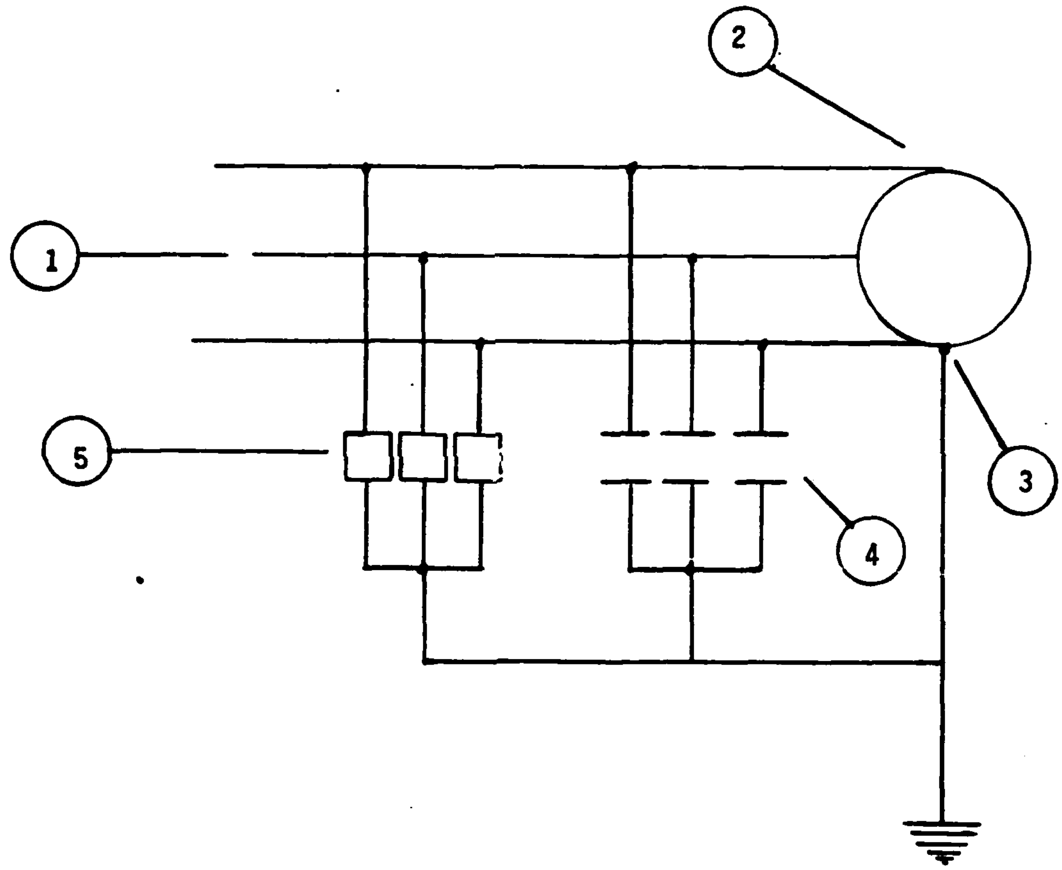


FIGURE 4

LIGHTNING PROTECTION FOR MOTORS

1. Overhead power line
2. Motor
3. Ground on motor frame
4. Lightning protective capacitors
5. Low-breakdown arresters

The item to be grounded should be bolted or brazed to the ground strap. Heavy asphalt paint should be applied to all connections to prevent corrosion. Resistance to grounds should be tested each year. If resistance exceeds 5 ohms the ground should be improved.

All metal parts of machines that may produce static electricity should be bonded and grounded. The nozzle of the flexible hose of the preservative oil spray system is grounded to protect against static electricity (see Figure 2). Bonding is electrically connecting two or more conducting objects with a conductor. Grounding is electrically connecting one or more conducting objects to a ground potential. Bonding keeps two items at the same potential to eliminate spark discharge. Grounding drains the static charges away. Ground resistance should not exceed 1,000,000 ohms for static grounding. Buried tanks need no special grounding.

Grounding of electrical circuits and equipment reduces the hazards of electrical shock and fire. A dangerous difference in potential between two objects is eliminated when the two objects are connected to a common ground.

The design which has been chosen reduces the possibility of fire and explosion in several ways. The gasoline is drained into a drain pan and then flows into a large storage tank. A screen over the drain pan and a flame arrester in the drain pipe reduce the chance of fire and explosion. The vapor-air mixture over the gasoline in the tank will be too rich to ignite most of the time. When this tank becomes full the gasoline is pumped into a tanker truck and removed.

The probability of a fire or explosion is further reduced by using only fresh (unused) preservative oil in the process. This is accomplished by using a reduced amount of preservative oil and coating the fuel tank with a spray rather than filling the entire tank. By spraying the tank three times with 3/4 gallon of preservative oil each time, rather than one time with 2¼ gallons, economical use of the oil results and a greater degree of safety is attained. Suppose one pint of gasoline remained in the fuel tank after draining. One spray of 2¼ gallons would leave (assuming one pint is undrainable) one pint consisting of one part gasoline to 18 parts of oil or about 5% gasoline. Three sprays of 3/4 gallon each (total volume of 2¼ gallons) would leave one pint consisting of one part gasoline to 216 parts of oil or about 0.5% gasoline. Using the predictive equations in the Appendix, the flashpoint of a 5% gasoline-oil mixture is 25 (Equation 1) or -19 (Equation 2) degrees Fahrenheit depending on the equation used. This indicates that the vapor-air mixture is in the explosive range for this concentration of gasoline. Using these same equations the predicted flashpoint of a 0.5% gasoline-oil mixture is either 97 (Equation 1) or 14 Fahrenheit (Equation 2). This indicates that the vapor-air mixture may (Equation 2) or may not (Equation 1) be in the explosive range for this concentration of gasoline. The flashpoints predicted by Equation 1 are close to those observed in used preservative oil. Equation 2 does not seem to be adequate.

This discussion has not considered all of the hazards of the proposed system. The next chapter will discuss and analyze the designed system's hazards in more detail.

CHAPTER IV

SAFETY ANALYSIS OF THE SYSTEM DESIGN

Failure Mode and Effects Analysis

Failure mode and effects analysis (FMEA) is an inductive reasoning method which uses a cause and effect relationship. Each component of the system is analyzed for potential failure causes and their effects. This report will be limited to qualitative FMEA although, generally, quantitative data may be applied to establish system reliability when failure rates for component failure modes are known.

The purpose of the FMEA is to insure that component failures will have minimal effect on the other components and on the entire system. Critical modes of failure can be established and can be eliminated or controlled. Effects of human actions will not be included in the FMEA.

The format for the FMEA is flexible. Generally, information and data are arranged in a table with appropriate headings. In this particular report the following headings will be used: component, failure mode, possible effects, criticality, and remarks. Most of these headings are self-explanatory with the possible exception of "criticality". The criticality of each failure mode indicates the effects to the system's ability to operate and the effects to the system's environment. The criticality of each failure mode will be indicated as critical (results in serious injuries or death to personnel, or in loss of the system; results in no or minor injuries to personnel, or in a slight degradation of system performance) or non-critical.

FAILURE MODE AND EFFECTS ANALYSIS

SUBSYSTEM: Gasoline Drain System

COMPONENT	FAILURE MODES	POSSIBLE EFFECTS	CRITICALITY	REMARKS
Drain Pan	Cracking	Gasoline leakage onto work area, possible fire when combined with ignition source.	Critical	Controlled by daily inspection of pan.
	Clogged screen	Gasoline overflows onto work area, possible fire when combined with ignition source.	Critical	Controlled by daily inspection of screen.
	Fire	Destruction of nearby vehicles, possible explosion in storage tank.	Critical	Ignition sources must be eliminated from area.
	Water contamination	Contamination of gasoline in storage tank.	Non-critical	Provide a weather shield over drain when not being used.
	Overflow	Spillage onto work area, possible fire when combined with ignition source.	Critical	Insure drain pipe and drain pan are large enough to hold maximum fuel tank capacity.

FAILURE MODE AND EFFECTS ANALYSIS

SUBSYSTEM: Gasoline Drain System

COMPONENT	FAILURE MODES	POSSIBLE EFFECTS	CRITICALITY	REMARKS
Tank	Explosion	Destruction of property, death or injury to personnel.	Critical	Insure flame arresters are used in drain pipe and in vent pipe.
	Rupture	Leakage of gasoline into ground, possible explosion or fire when ignition source is present.	Critical	Inspect tank before installation, exercise care during installation, provide adequate vent.
	Structural, i.e. cracking, fracture, etc.	Leakage of gasoline into ground, possible explosion or fire when ignition source is present.	Critical	Provide adequate anchorage and cover (soil and concrete) during installation, assure adequate strength of material and quality of workmanship.
	Overflow	Gasoline spillage onto work area, possible explosion or fire when ignition source is present.	Critical	Install gauge, establish schedule for emptying tank.

FAILURE MODE AND EFFECTS ANALYSIS

SUBSYSTEM: Gasoline Drain System

COMPONENT	FAILURE MODES	POSSIBLE EFFECTS	CRITICALITY	REMARKS
Tank (cont.)	Corrosion	Structural failure, loss of gasoline, possible fire or explosion when combined with ignition source.	Critical	Properly coat tank before installation.

FAILURE MODE AND EFFECTS ANALYSIS

SUBSYSTEM: Fuel Tank Preservation

COMPONENT	FAILURE MODES	POSSIBLE EFFECTS	CRITICALITY	REMARKS
Preservative oil storage tank	Rupture	Leakage of oil into ground and ground water, possible fire when combined with ignition source.	Critical	Inspect tank before installation, exercise care during installation, provide proper vent.
	Structural, i.e. cracking, fracture, etc.	Slow seeping of oil into ground and ground water, possible fire when combined with ignition source.	Critical	Provide adequate anchorage and cover during installation, assure adequate strength of material and quality of workmanship.
	Corrosion	Weakening of tank, structural failure with release of oil, possible fire when combined with ignition source.	Critical	Properly coat tank before installation.
	Overflow during filling	Possible fire if exposed to open flame.	Critical	Clearly label fill pipe with maximum tank capacity, provide proper gauge.

FAILURE MODE AND EFFECTS ANALYSIS

SUBSYSTEM: Fuel Tank Preservation

COMPONENT	FAILURE MODES	POSSIBLE EFFECTS	CRITICALITY	REMARKS
Tank gauge	Fail in "full" position	Lack of oil to operate system, system shut down until more oil is delivered.	Non-critical	Insure good quality gauge, check gauge when filling tank.
	Fail in "empty" position	Overfilling of tank, possible fire if exposed to open flame.	Critical	Instruct operator to visually watch fill pipe as well as gauge when filling.
Tank vent	Clogged	Overpressure and rupture of tank during severe fire.	Critical	Check vent daily.

FAILURE MODE AND EFFECTS ANALYSIS

SUBSYSTEM: Fuel Tank Preservation

COMPONENT	FAILURE MODES	POSSIBLE EFFECTS	CRITICALITY	REMARKS
Pump	Explosion	Destruction of pump, injury to personnel.	Critical	Pump must be properly maintained and operated at rated speed.
	Fire	Damage to pump, possible fire if combustibles are present.	Critical	Follow lubrication schedule, change packing when recommended by the manufacturer.
	Leakage	Loss of oil, possible fire if exposed to open flame.	Critical	Insure maintenance schedule is followed.

FAILURE MODE AND EFFECTS ANALYSIS

SUBSYSTEM: Fuel Tank Preservation

COMPONENT	FAILURE MODES	POSSIBLE EFFECTS	CRITICALITY	REMARKS
Relief valve	Fail closed	System overpressurizes, damage to fittings, possible loss of oil.	Critical	Insure adequate quality, properly maintain valve.
	Fail open	Inadequate pressure to properly spray and coat fuel tanks.	Critical	Same.

FAILURE MODE AND EFFECTS ANALYSIS

SUBSYSTEM: Fuel Tank Preservation

COMPONENT	FAILURE MODES	POSSIBLE EFFECTS	CRITICALITY	REMARKS
Controller	Fail open	Oil fails to be pumped.	Critical	Ensure quality, inspect and maintain on regular schedule.
	Fail closed	Excess oil pumped.	Non-critical	Operator can use emergency shut off.
Flexible hose	Rupture	Oil sprayed onto work area, system failure, possible fire if open flame is present.	Critical	Ensure hose is compatible with oil, inspect daily for wear and cracks.
Nozzle	Clogged	Failure to properly coat fuel tank.	Critical	Inspect daily, provide a filter in line.

FAILURE MODE AND EFFECTS ANALYSIS

SUBSYSTEM: Used Oil Drain System

COMPONENT	FAILURE MODES	POSSIBLE EFFECTS	CRITICALITY	REMARKS
Drain pan	Cracking	Oil leakage onto work area, possible fire when combined with ignition source.	Critical	Inspect pan daily, provide drain into used oil storage tank.
	Clogged screen	Oil overflows onto work area, possible fire when combined with ignition source.	Critical	Inspect screen daily.
	Fire	Damage to personnel and equipment.	Critical	Eliminate ignition sources, provide portable fire extinguishers.
Used oil storage tank	Explosion	Damage to property and equipment, injury and death to personnel.	Critical	Insure flame arresters are used in drain pipe and in vent pipe, use "reticulated foam" in tank.

FAILURE MODE AND EFFECTS ANALYSIS

SUBSYSTEM: Used Oil Drain System

COMPONENT	FAILURE MODES	POSSIBLE EFFECTS	CRITICALITY	REMARKS
Tank	Rupture	Leakage of oil into ground, possible explosion or fire when combined with ignition scurce.	Critical	Provide venting, inspect tank and handle with care during installation.
	Structural, i.e. cracking, fracture, etc.	Seeping of oil into ground, possible explosion or fire when combined with ignition source.	Critical	Provide adequate anchorage and cover, assure adequate strength of material and quality of workmanship.
	Overflow	Oil spillage onto work area, possible fire if ignition source is present.	Critical	Install gauge, establish schedule for emptying tank.
	Corrosion	Structural failure, leakage of oil into ground, possible explosion or fire when combined with ignition source.	Critical	Properly coat tank before installation.

FAILURE MODE AND EFFECTS ANALYSIS

SUBSYSTEM: Fuel Tank Preservation

COMPONENT	FAILURE MODES	POSSIBLE EFFECTS	CRITICALITY	REMARKS
Lines and connections	Faulty connection	Oil leakage, possible fire when combined with flame source.	Critical	Hydrostaticly test system before use.
	Blockage	System failure, insufficient oil.	Critical	Install filter in line before pump.
Wiring	Loose connection	Possible sparking, combined with fuel source results in fire.	Critical	Ensure proper installation.
	Insulation failure	Same	Same	Same

FAILURE MODE AND EFFECTS ANALYSIS

SUBSYSTEM: Transfer Pumps

COMPONENT	FAILURE MODES	POSSIBLE EFFECTS	CRITICALITY	REMARKS
Gasoline pump	Explosion	Damage to property and equipment.	Critical	Use explosion-proof pump and motor, maintain properly.
	Leakage	Possible fire when combined with ignition source.	Critical	Properly inspect and maintain pump.
Used oil pump	Same	Same	Critical	Same

FAILURE MODE AND EFFECTS ANALYSIS

SUBSYSTEM: Lightning Arresters and Grounds

COMPONENT	FAILURE MODES	POSSIBLE EFFECTS	CRITICALITY	REMARKS
Ground strap	Corrosion	Failure to provide adequate ground.	Critical	Use noncorrosive material, apply asphalt paint.
Lightning protective capacitors	Fail short	Failure to provide protection against lightning strike.	Critical	Check svstem after electrical storms.
Low-breakdown arresters	Fail short	Failure to provide protection against lightning strike.	Critical	Check system after electrical storms.

Fault Tree Analysis

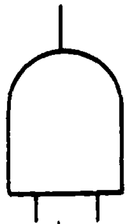
Fault tree analysis is one of the most advanced techniques for performing safety analyses. It is a type of safety logic diagram that traces all events and combination of events that can lead to a defined undesired event. Fault tree analysis is primarily a qualitative technique (4) which identifies areas that need further accident prevention attention. Quantitative results can be obtained by applying event probabilities to calculate the overall probability of the defined undesired event. Since the system design involves many human activities for which probabilities of failure are difficult to establish, this report will use a qualitative approach.

The fault tree starts by placing an undesired event at the top of the tree, such as a fire or explosion which will be the two events analyzed in this report. The tree that is built is a logical sequence of events that may occur. The tree proceeds until either independent events are reached, data is lacking, or further events contribute insignificantly.

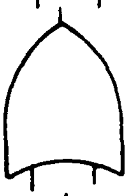
The ten basic fault tree symbols (9) are shown in Figure 5. The fault tree determines single point failures which are apparent due to the chain of OR gates between the undesired event and the single point failure. The chain can be broken by providing events which require AND gates.

Mathematical expressions representing the fault tree events are developed using Boolean algebra. The AND gates indicate the events should be connected by the (.) symbol and the OR gages indicate the events should be connected by the (+) symbol.

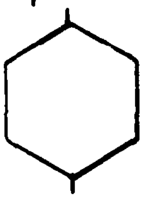
Fault trees are developed for the following undesired events: preservative oil fire, gasoline fire, used oil fire, explosion in gasoline drain area, and used oil storage tank explosion. These events are considered to be the most potentially damaging to personnel and equipment.



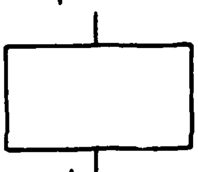
A logical AND relation. An AND gate.



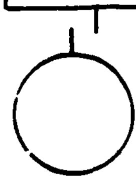
A logical OR relation. An OR gate.



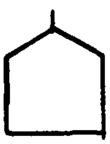
A conditional probability symbol where an event will occur provided another event occurs.



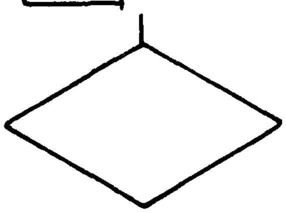
An event usually caused by contributing events.



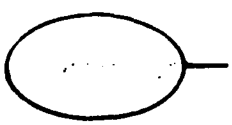
An event which is a basic or primary failure mode.



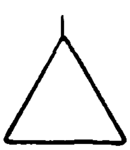
An event that is normally expected to occur.



An event where analysis is stopped. Further knowledge lacking or considered inconsequential.



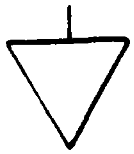
Indicates and stipulates restrictions. The restriction must be fulfilled with an AND gate, before the event can occur. With an OR gate, the stipulation may be that the event will not occur in the presence of both or all inputs simultaneously.



A connecting symbol to another part of the tree. Has the same functions and numerical values.

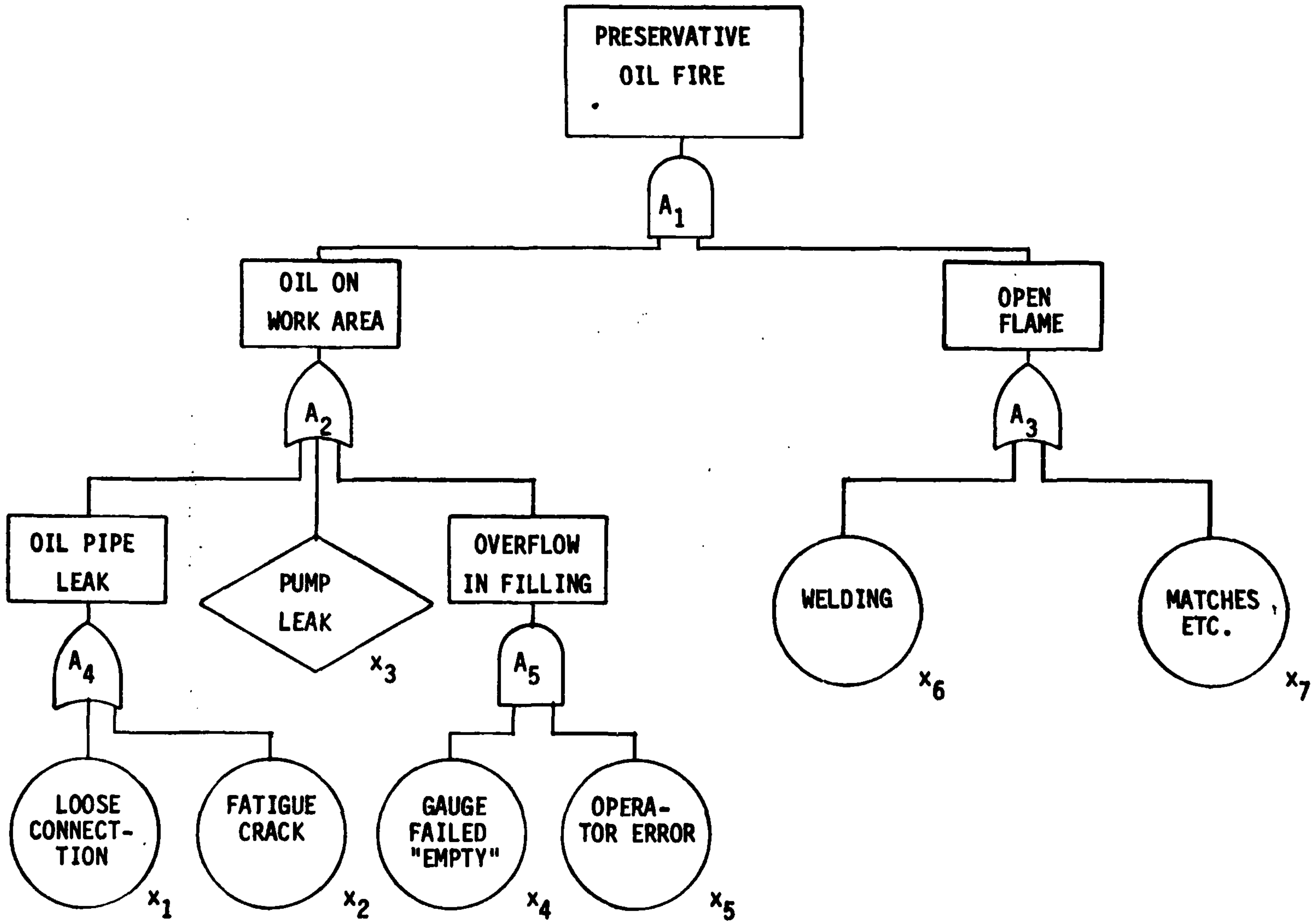
FIGURE 5

FAULT TREE SYMBOLS



A connecting symbol to another part of the fault tree within the same major branch. Has the same functions and sequence of events, but not numerical values.

FIGURE 5
(Continued)


PRESERVATIVE OIL FIRE
A_1
OIL ON WORK AREA
OPEN FLAME
A_2
A_3
OIL PIPE LEAK
PUMP LEAK
x_3
OVERFLOW IN FILLING
WELDING
x_6
MATCHES ETC.
x_7
A_4
A_5
LOOSE CONNECT-TION
x_1
FATIGUE CRACK
x_2
GAUGE FAILED "EMPTY"
x_4
OPERA-TOR ERROR
x_5

Undesired event: Preservative Oil Fire.

Boolean Expression for Fault Tree:

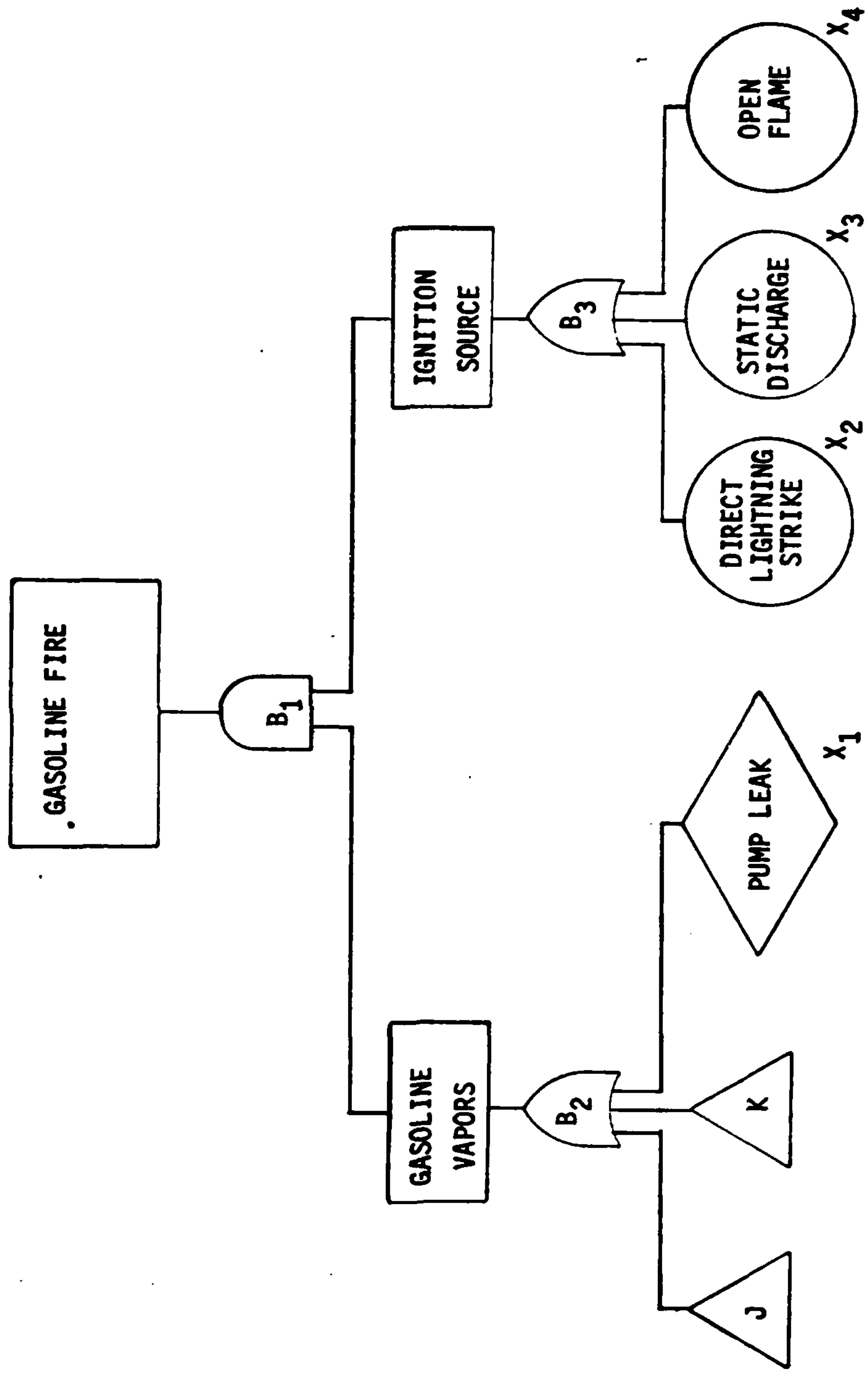
$$A_1 = A_2 \cdot A_3$$

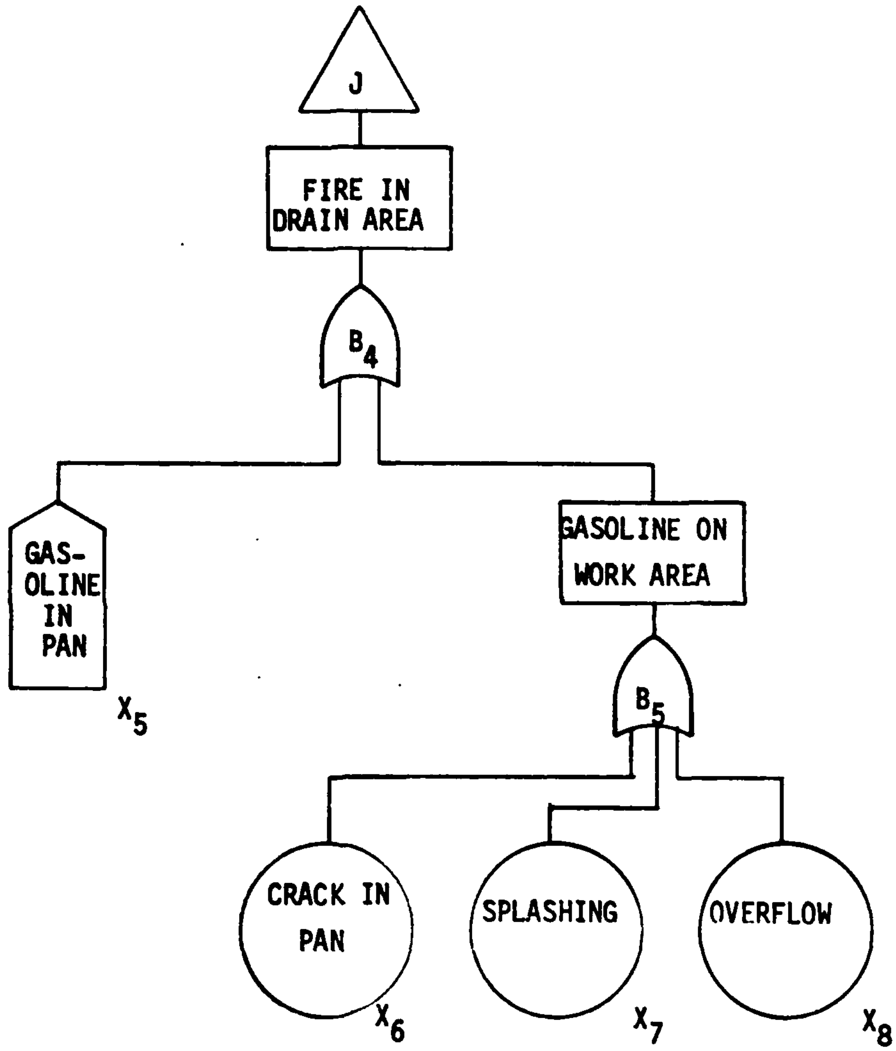
$$A_1 = (x_1 + A_4 + A_5) \cdot (x_6 + x_7)$$

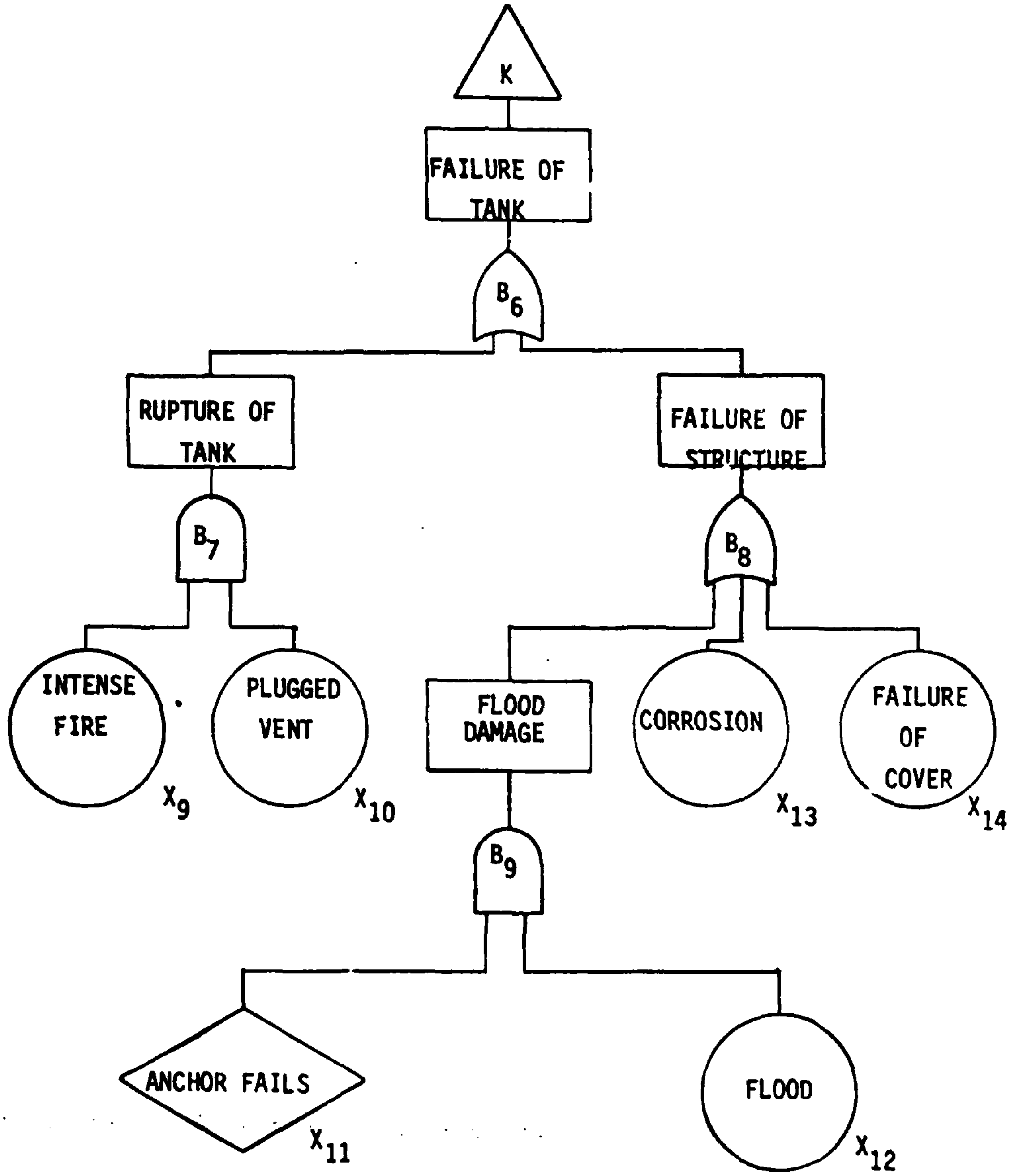
$$A_1 = (x_1 + (x_2 + x_3) + (x_4 \cdot x_5)) \cdot (x_6 + x_7)$$

$$A_1 = (x_1 + x_2 + x_3 + (x_4 \cdot x_5)) \cdot (x_6 + x_7)$$

The first factor is the combination of events which lead to oil being on the work area. The second factor is the combined events which could ignite the oil. Only open flame sources are considered because the oil must be heated before enough vapor is present for ignition. The sources of ignition are controllable and could be reduced to a very small likelihood.


GASOLINE FIRE
B_1
IGNITION SOURCE
B_3
DIRECT LIGHTNING STRIKE
X_2
STATIC DISCHARGE
X_3
OPEN FLAME
X_4
GASOLINE VAPORS
B_2
PUMP LEAK
X_1
K
J


J
FIRE IN DRAIN AREA
B_4
GAS-OLINE IN PAN
X_5
GASOLINE ON WORK AREA
B_5
CRACK IN PAN
X_6
SPLASHING
X_7
OVERFLOW
X_8


K
FAILURE OF TANK
B_6
RUPTURE OF TANK
FAILURE OF STRUCTURE
B_7
B_8
INTENSE FIRE
X_9
PLUGGED VENT
X_{10}
FLOOD DAMAGE
CORROSION
X_{13}
FAILURE OF COVER
X_{14}
B_9
ANCHOR FAILS
X_{11}
FLOOD
X_{12}

Undesired event: Gasoline Fire

Boolean Expression for Fault Tree:

$$B_1 = B_2 \cdot B_3$$

$$B_1 = (J + K + x_1) \cdot (x_2 + x_3 + x_4)$$

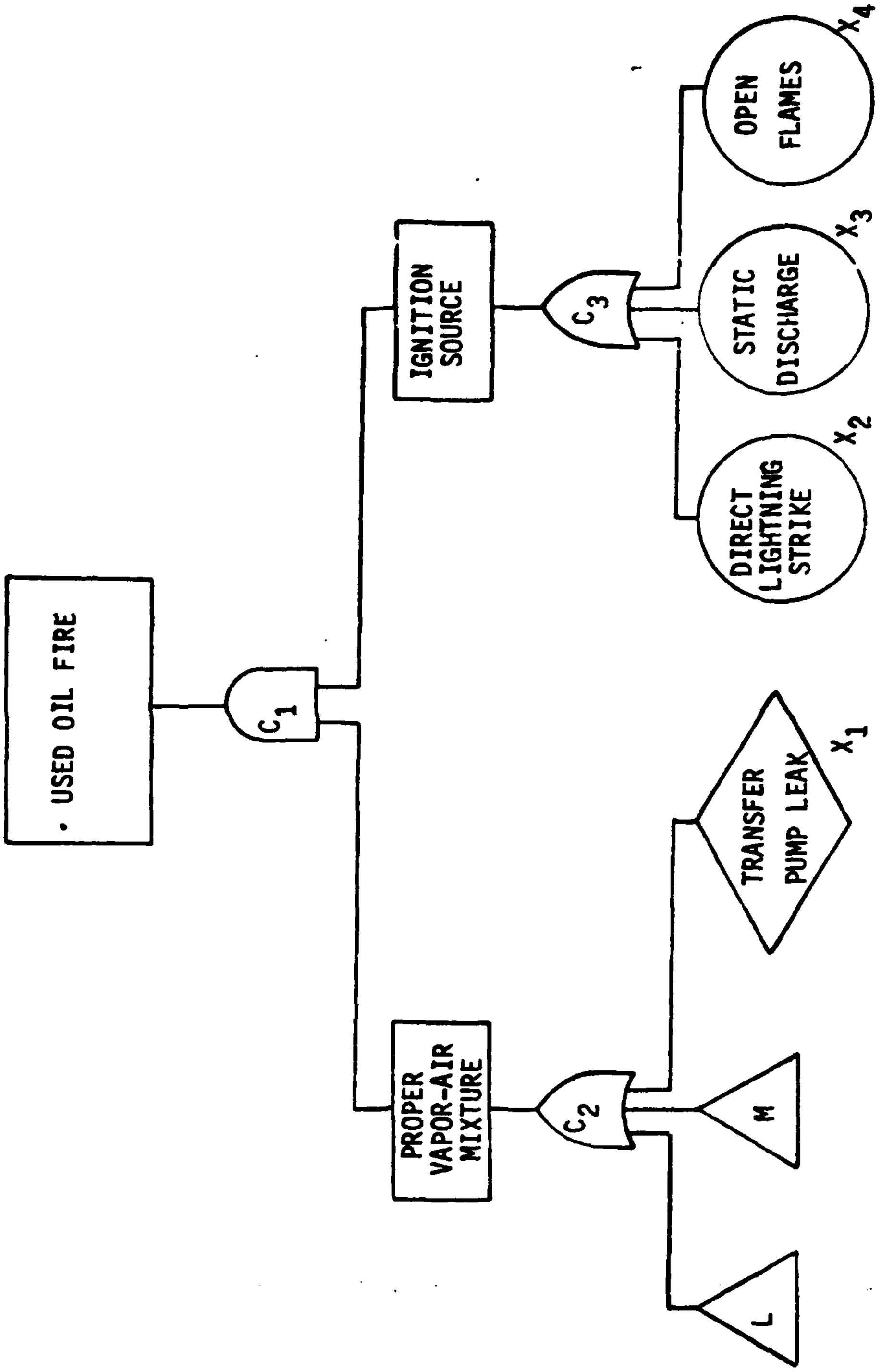
$$B_1 = ((B_4 + B_6 + x_1) \cdot (x_2 + x_3 + x_4)$$

$$B_1 = ((x_5 + B_5) + (B_7 + B_8) + x_1) \cdot (x_2 + x_3 + x_4)$$

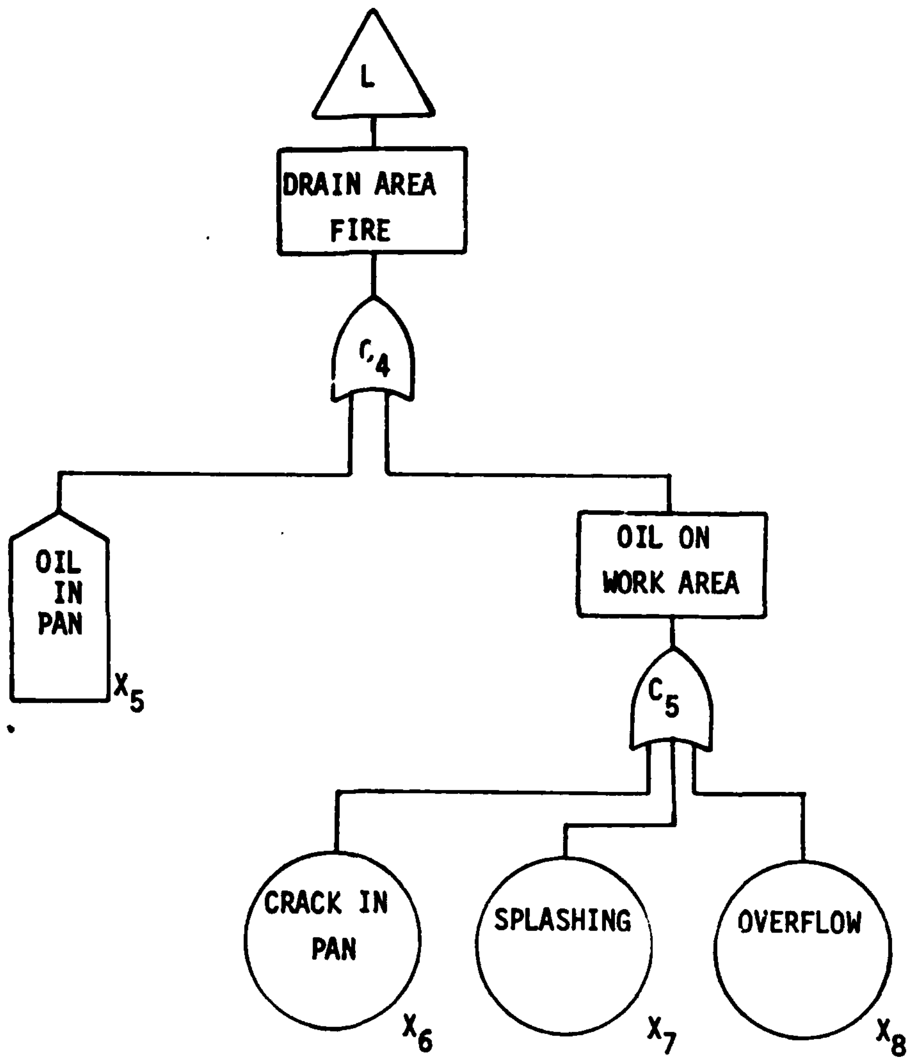
$$B_1 = (x_5 + (x_6 + x_7 + x_8) + (x_9 \cdot x_{10}) + (B_9 + x_{13} + x_{14}) + x_1) \cdot (x_2 + x_3 + x_4)$$

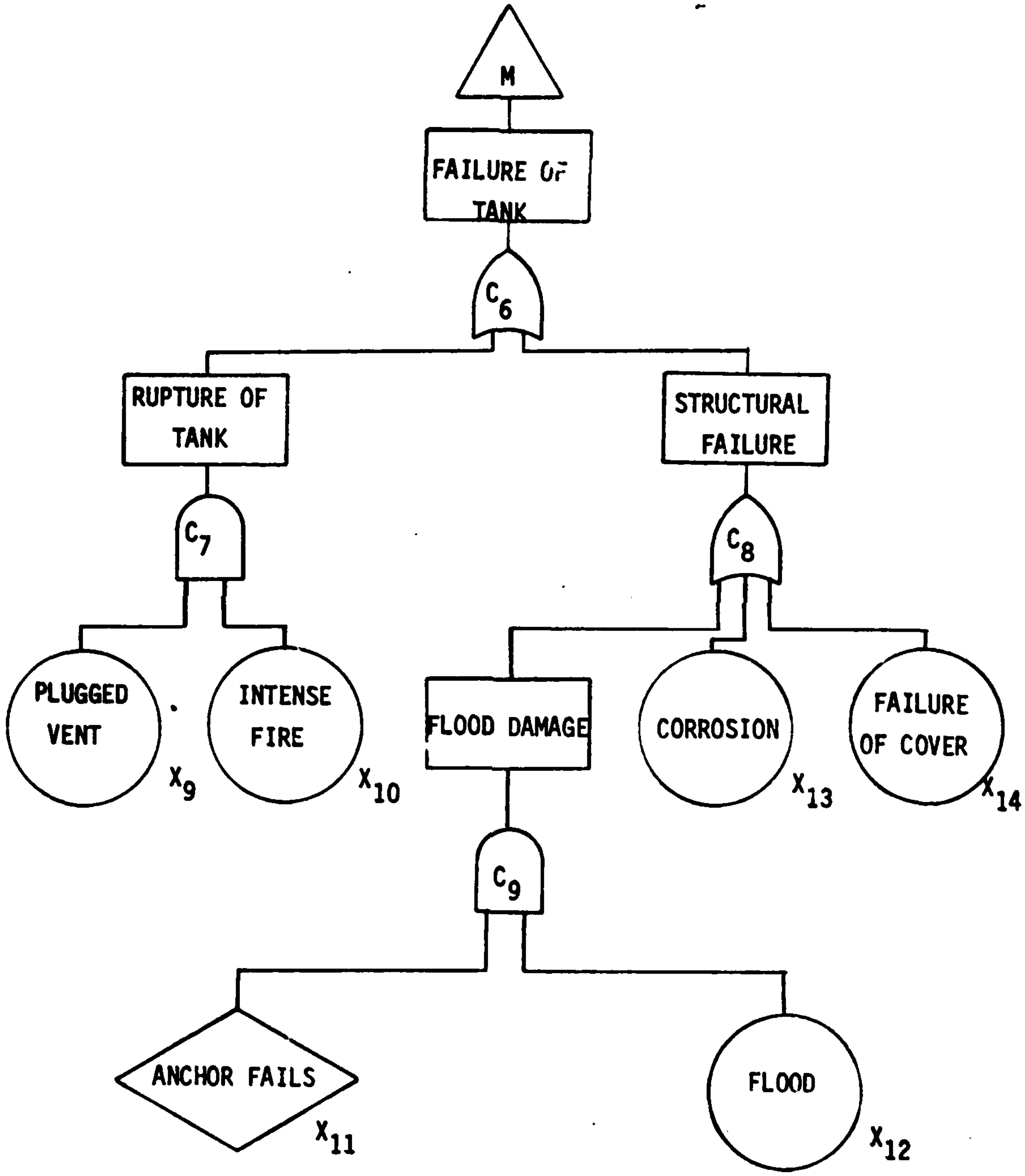
$$B_1 = (x_5 + x_6 + x_7 + x_8 + (x_9 \cdot x_{10}) + (x_{11} \cdot x_{12}) + x_{13} + x_{14} + x_1) \cdot (x_2 + x_3 + x_4)$$

Again the first factor is the combination of events which contribute to the presence of fuel for the fire. During the draining of each fuel tank these conditions exist. Therefore it is essential to minimize the ignition sources.



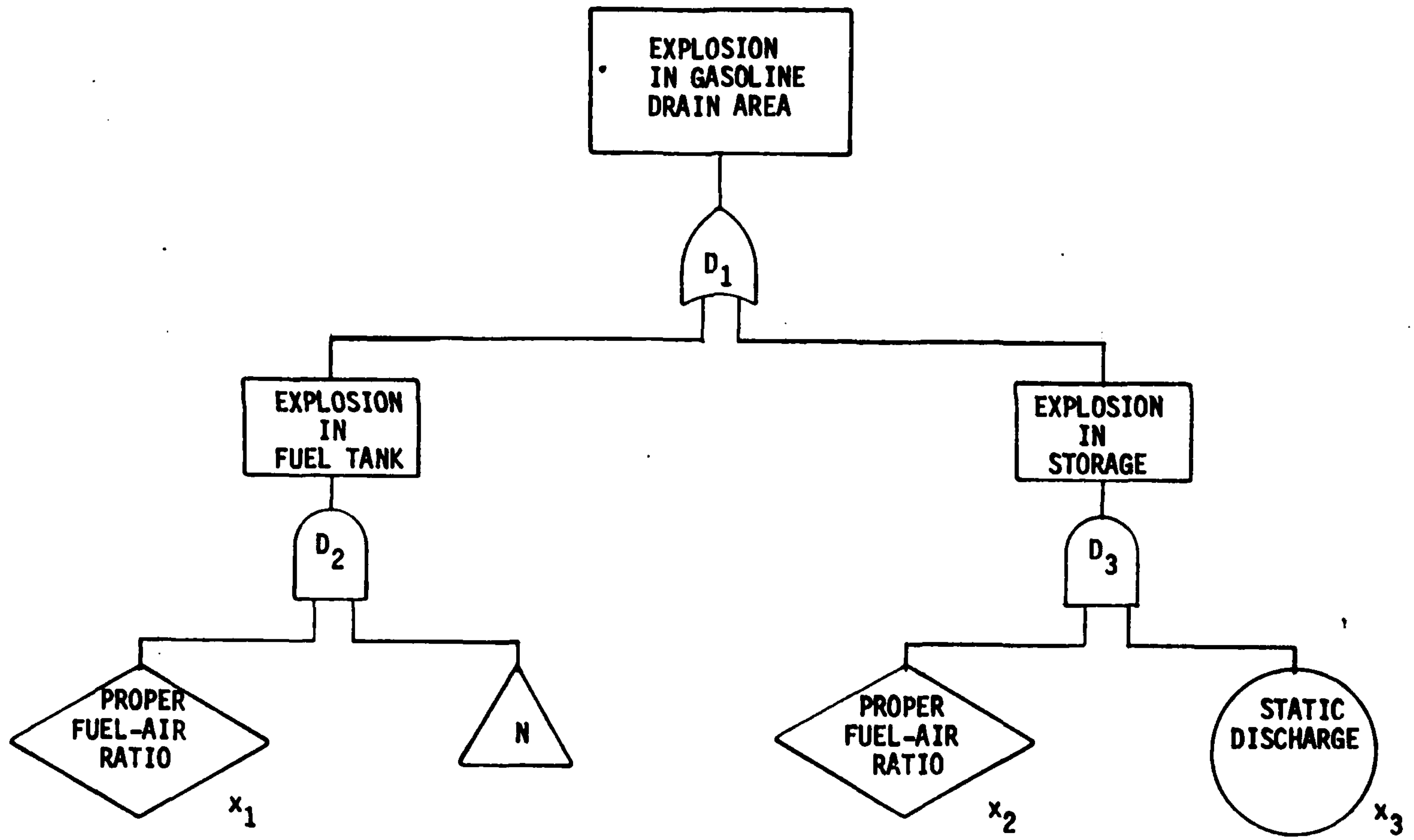
USED OIL FIRE
C_1
IGNITION SOURCE
C_3
DIRECT LIGHTNING STRIKE
X_2
STATIC DISCHARGE
X_3
OPEN FLAMES
X_4
PROPER VAPOR-AIR MIXTURE
C_2
TRANSFER PUMP LEAK
X_1
M
L

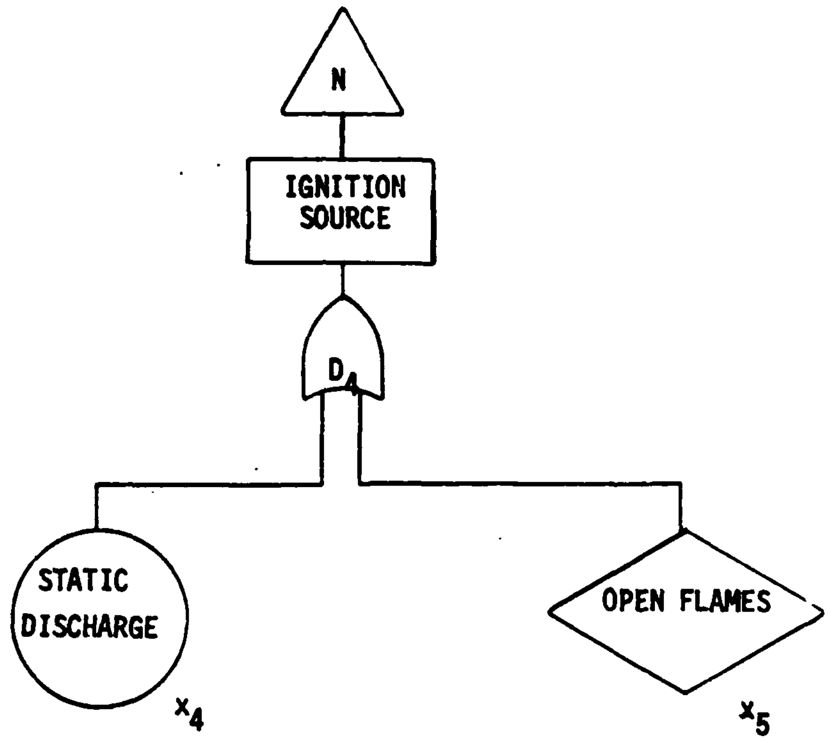

L
DRAIN AREA FIRE
C4
OIL IN PAN
X5
OIL ON WORK AREA
C5
CRACK IN PAN
X6
SPLASHING
X7
OVERFLOW
X8


M
FAILURE OF TANK
C_6
RUPTURE OF TANK
STRUCTURAL FAILURE
C_7
C_8
PLUGGED VENT
X_9
INTENSE FIRE
X_{10}
FLOOD DAMAGE
CORROSION
X_{13}
FAILURE OF COVER
X_{14}
C_9
ANCHOR FAILS
X_{11}
FLOOD
X_{12}

Undesired event: Used Oil Fire.

It is evident that the fault tree for "used oil fire" is identical to the fault tree for "gasoline fire" and, therefore, the same Boolean expression results. Ignition sources must be kept away from the drain area, especially during and shortly after draining the used oil from a vehicle fule tank.


EXPLOSION
IN GASOLINE
DRAIN AREA
D_1
EXPLOSION
IN
FUEL TANK
EXPLOSION
IN
STORAGE
D_2
D_3
PROPER
FUEL-AIR
RATIO
x_1
N
PROPER
FUEL-AIR
RATIO
x_2
STATIC
DISCHARGE
x_3


N
IGNITION SOURCE
D_4
STATIC DISCHARGE
x_4
OPEN FLAMES
x_5

Undesired event: Explosion in Gasoline Area.

Boolean Expression for Fault Tree:

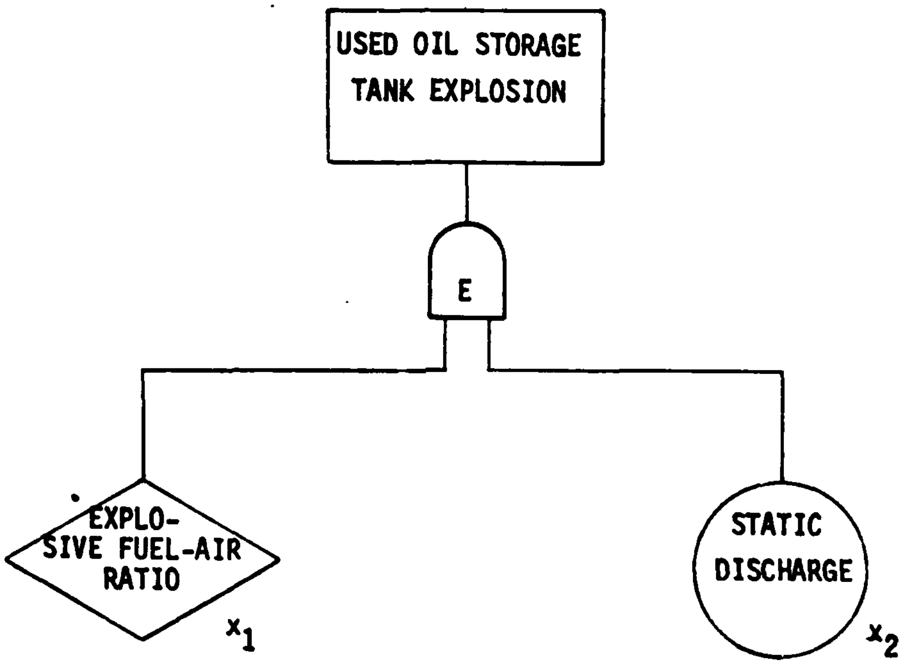
$$D_1 = D_2 + D_3$$

$$D_1 = (x_1 . N) + (x_2 . x_3)$$

$$D_2 = (x_1 . D_4) + (x_2 . x_3)$$

$$D_2 = (x_1 . (x_4 + x_5)) + (x_2 . x_3)$$

The probability of event x_1 (explosive fuel-air ratio) is certain to have a value of 1.0 sometime during the servicing period, but the probability of having an ignition source in the vehicle fuel tank is very low. Explosive fuel-air mixtures in the gasoline storage tank can be expected only when the tank is practically empty. Otherwise, the mixture is too rich. Caution is required during periods when the tank is being emptied because the fuel-air mixture in the tank is diluted with air and an explosive mixture is likely to result.


USED OIL STORAGE TANK EXPLOSION
E
EXPLO-SIVE FUEL-AIR RATIO
x1
STATIC DISCHARGE
x2

Undesired event: Used Oil Storage Explosion.

Boolean Expression for Fault Tree:

$$E = x_1 \cdot x_2$$

The probability of event x_1 (explosive fuel-air ratio in the storage tank) is much higher for this storage tank than any other since the used oil can be expected to have a flashpoint in the temperature range normally encountered (see Appendix for predicted flashpoints of oil-gasoline mixtures). For this reason the use of foam is recommended in the design. Using flame arresters in the drain and vent pipes limits the ignition source to static discharge and this has a small probability of occurrence in a buried tank.

CHAPTER V

DISCUSSION OF RESULTS OF ANALYSIS

Now that a system has been designed and analyzed in some detail, a comparison to the present system must be made to determine whether a significant increase in safety would result. The systems can best be compared by examining the fire and explosive hazards which are listed in the failure mode and effects analysis and which appear as the top events in the fault tree analysis.

The probability of a preservative oil fire is greater in the present system than in the designed system. In the present system the preservative oil becomes contaminated with gasoline after the first group of vehicle fuel tanks are processed. The preservative oil becomes richer and richer in gasoline with each vehicle fuel tank that is preserved. The flashpoint drops from 400 degrees Fahrenheit for pure preservative oil, to 74 degrees Fahrenheit (predicted from equations given in Appendix) for preservative oil contaminated with one percent gasoline. Preservative oil contaminated with ten percent gasoline (maximum allowed by military specification) has a predicted flashpoint of 5 degrees Fahrenheit. Because of this increase in volatility of preservative oil contaminated with gasoline, the ignition temperature is reduced. Sparks which would not ignite pure preservative oil may ignite oil-gasoline mixtures. Also, preservative oil is handled repeatedly in the present system. Preservative oil is exposed to the open air and an opportunity for spillage exist every time a fuel tank is filled.

The total likelihood of a fire involving preservative oil in the proposed system includes the probabilities of fresh and used preservative oil fires. A fresh preservative oil fire in the designed system is seen to be unlikely, as shown by fault tree analysis, primarily because of the need for open sources of flame and the unlikely presence of exposed preservative oil. A used preservative oil fire in the designed system is more likely than a fire involving unused oil, but this type of fire would involve relatively small quantities of used preservative oil since most of the oil quickly drains into the preservative oil storage tank which is protected from a fire following the liquid flow into the tank with a flame arrester in the drain pipe and "reticulated foam" in the tank.

The probability of a gasoline fire is higher in the present system (as prescribed by military specification) than in the proposed design. In the present system gasoline is pumped out of each fuel tank into a tanker truck using a gasoline motor-driven pump. The remaining gasoline is supposed to be drained by removing the drain plug (5). However, inspection revealed that the drain plug is not always removed. This actually reduces the probability of a gasoline fire by removing the exposure opportunity, but it certainly contaminates the preservative oil at a much faster rate. When the preservative oil is drained, though, it is collected in a pan placed under the vehicle, and then pumped into the tanker truck. Thus, the exposure of gasoline to the air per vehicle is greater in the present system than in the designed system. The probability of a fire resulting from a pump failure is small if the pump is properly operated and maintained. Nevertheless, pumping is required much more frequently in the present system (with each vehicle processed) than in the proposed system (when the storage tank is full). Furthermore, the designed system's principle of draining gasoline into an underground storage tank eliminates the processes of metal to metal (nozzle to tank) contact, bonding strap hookup, and pumping gasoline through a gasoline motor-driven pump with every fuel tank processed. Clearly, the proposed draining technique offers a safety advantage by reducing the handling of gasoline.

The probability of an explosion in the tank of the tanker truck holding gasoline is greater than the probability of an explosion in the gasoline storage tank of the proposed system. Primarily this is the result of more sources and the slower dissipation of static electricity in the tanker truck. Static electricity is created by the movement of gasoline through the hose when being pumped and when the gasoline is splashed onto the walls of the tank when the tanker truck is moved. A lesser amount of static electricity is generated when gasoline is drained into a tank because it is moving at a slower speed than when it is pumped through a hose. The dissipation of static electricity is much slower through a tank and over rubber truck tires to the ground than it is directly through a tank into the ground. Most of the time the fuel-air mixtures in the gasoline storage tank will be too rich to ignite. Should an explosion occur, however, a buried tank offers some protection to near-by structures and personnel.

Probably the single most critical need for a new system is demonstrated by the probability of an explosion in the tanker truck holding used preservative oil. The expected flashpoint of the used preservative oil, as discussed earlier, varies from 400 degrees Fahrenheit for fresh preservative oil to about 5 degrees Fahrenheit for a mixture of preservative oil and ten percent gasoline. Most of the time the flashpoint is below 74 degrees Fahrenheit. Assuming that the temperature corresponding to the upper limit of flammability is 70 degrees higher than the flashpoint (as is the case for gasoline), the vapor space above the used oil in the tank of the tanker truck is in the explosive range over 90 percent of the time. The probability of explosion in the fresh oil storage tank is very low (the oil would need to be heated to 400 degrees Fahrenheit) and was not even considered in the fault tree analysis. The probability of an explosion in the used oil storage tank is low because of the use of flame arresters in the drain and vent pipes and the use of "reticulated foam" over the used preservative oil.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

This report has shown clearly that vehicle fuel tanks can be preserved efficiently and safely. It has demonstrated the value of using preliminary hazard analysis, failure mode and effects analysis, and fault tree analysis in selecting and testing a design for safety.

If the requirement exists to preserve vehicle fuel tanks, there should be a system designed especially for this purpose. Installation of a new system may be very expensive, but it should be cost effective when the cost of operating and maintaining the present system and the cost of future accidents are analyzed for a period of several years.

Recommendations

A cost effectiveness study should be accomplished to determine if the proposed system for conducting preservation of vehicle fuel tanks could be economically installed and operated. The principal costs of the proposed system would be the costs of buying and installing the underground tanks and the salaries of the operators of the system. The total cost of the proposed system would involve a detailed study which is outside the scope of this report.

An investment has already been made in the present system, which gives it some initial advantage as being considered as the preferred system. However, practically all of this investment involves the two tanker trucks which could be used for their intended purposes without a monetary loss if the new design is adopted.

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APPENDIX

PREDICTED FLASHPOINTS OF OIL-GASOLINE MIXTURES

Hu and Burns (11) developed a predictive method for calculating the flashpoints of distillate blends based upon data from five refineries. The number or components in each blend varied from five to eight. A total of ninety-seven blends were studied in developing the blending equation.

The equation for predicting flashpoints of mixtures is:

$$T_b^{1/x} = \sum V_i T_i^{1/x} \qquad \text{Equation 1.}$$

where:

T_b is the flashpoint of the blend (degrees Rankine),
T_i is the flashpoint of component "i" (degrees Rankine),
V_i is the volume fraction of component "i",
x is a constant depending upon the refinery which produced the stocks.

An average value of -0.06 is used in the calculations of the flashpoints graphed in Figure 6.

Sample Calculation

Find the flashpoint of a 95% - 05% oil-gasoline mixture.

T_{oil} is 860 degrees Rankine,
T_{gas} is 405 degrees Rankine,
V_{oil} is 0.95,
V_{gas} is 0.05.

$$T_b^{1/-.06} = .95(860)^{1/-.06} + .05(405)^{1/-.06}$$
$$T_b = (1.1733 \times 10^{-49} + 1.7433 \times 10^{-45})^{-.06}$$
$$T_b = (1.7434 \times 10^{-49})^{-.06}$$
$$T_b = 485 \text{ degrees Rankine or 25 degrees Fahrenheit.}$$

Wickey and Chittenden (22) developed a method to estimate the flashpoint of blends of petroleum products. Experimental flashpoints for 162 binary and ternary blends were used to determine the predictive equations. Although good results were obtained with blends of components differing by as much as 345 degrees Fahrenheit in flashpoint, the method was unsatisfactory for blends of very light naphtha and asphalt. Therefore, this method is not very suitable for predicting flashpoints of gasoline mixtures.

The flashpoint index is obtained from the equation:

$$\log_{10} I = -6.1188 + 4345.1/(T + 383) \qquad \text{Equation 2.}$$

where:

I is the flashpoint blending index,
T is the flashpoint of a stock or blend (degrees Fahrenheit).

The index for each stock is determined from its flashpoint and substituted into the blending equation:

$$I_b = V_g I_g + V_o I_o \qquad \text{Equation 3.}$$

where:

I_b is the flashpoint index of the blend,
I_g is the flashpoint index of gasoline,
I_o is the flashpoint index of preservative oil,
V_g is the volume fraction of gasoline,
V_o is the volume fraction of preservative oil.

Calculated flashpoints, using Equations 1 and 2, are graphed in Figure 6.

Sample Calculation

Find the flashpoint of a 95% - 05% oil-gasoline mixture.

T_{oil} is 400 degrees Fahrenheit,
T_{gas} is -55 degrees Fahrenheit,
V_{oil} is 0.95,
V_{gas} is 0.05.

The flashpoint indexes of preservative oil and gasoline must be determined using Equation 2.

$$\log_{10} I_o = -6.1188 + 4345.2/(400 + 383)$$

$$\log_{10} I_o = -.5694$$

$$I_o = 0.2695$$

$$\log_{10} I_g = -6.1188 + 4345.2/(-55 + 383)$$

$$\log_{10} I_g = 7.1288$$

$$I_g = 1.3452 \times 10^7$$

Now the flashpoint blending index is determined using Equation 3.

$$I_b = (.05)(1.3452 \times 10^7) + (.95)(.2695)$$

$$I_b = 6.726 \times 10^5$$

The flashpoint of the mixture can now be found by substituting the value of 6.726×10^5 for I_b in Equation 2 and solving for T.

$$\log_{10} (6.726 \times 10^5) = -6.1188 + 4345.2/(T + 383)$$

$$5.828(T - 383) = -6.1188(T - 383) + 4345.2$$

$$11.947\ T = 4345.2 - (11.947)(383)$$

$$11.947\ T = -230.5$$

$T = -19.3$ degrees Fahrenheit.

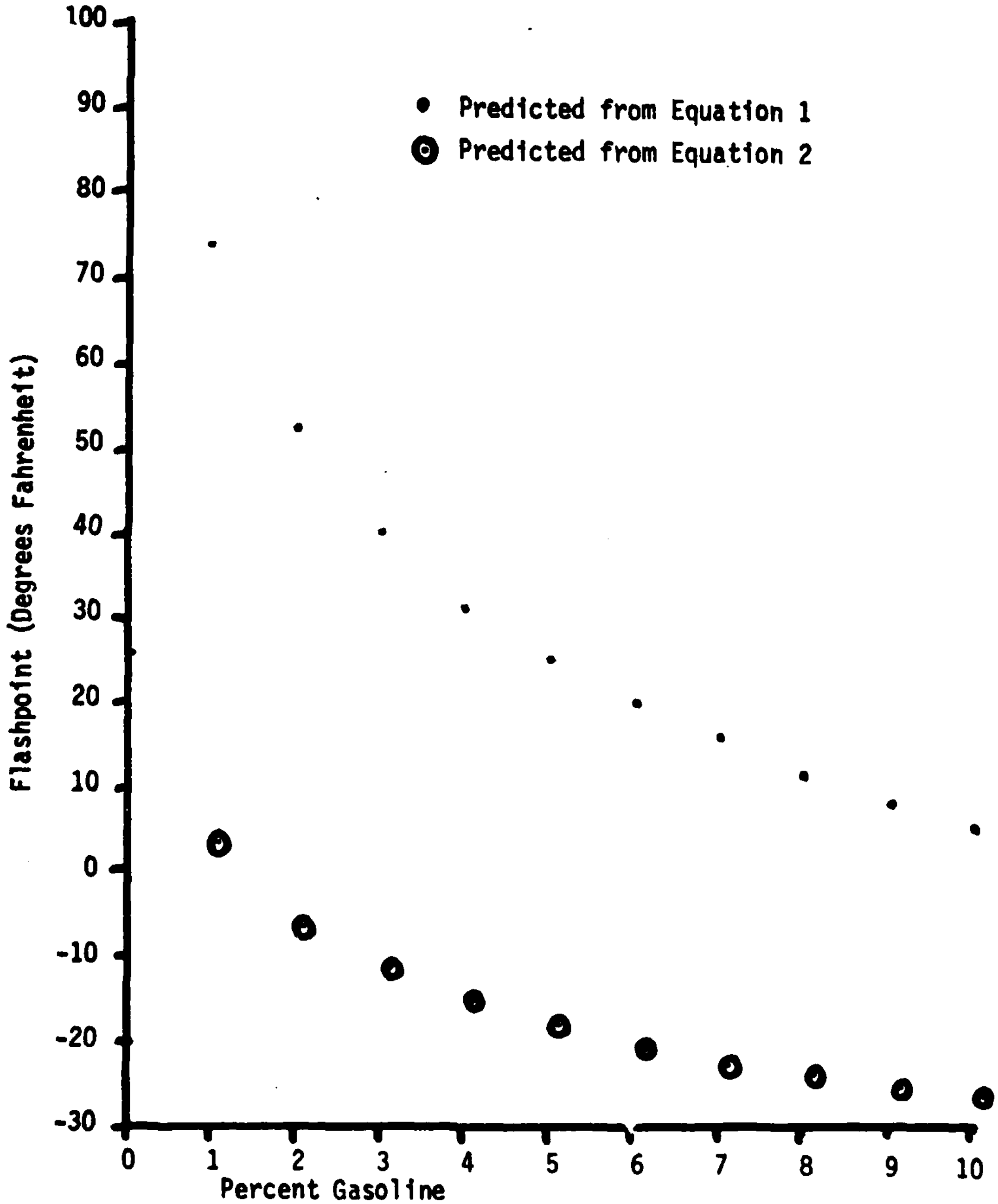

FIGURE 6

PREDICTED FLASHPOINTS OF OIL-GASOLINE MIXTURES